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Future Mission Trends and Their Implications for the Deep Space Network

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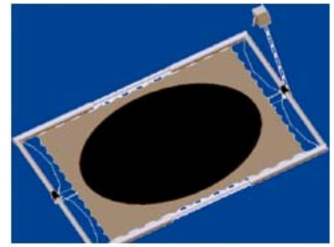
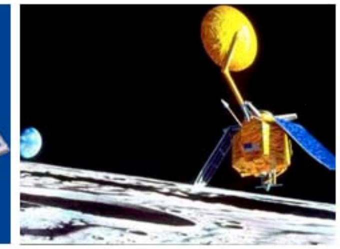
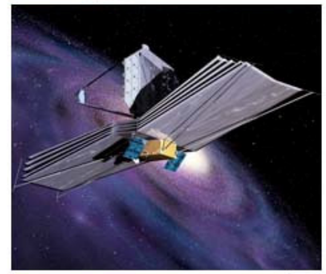
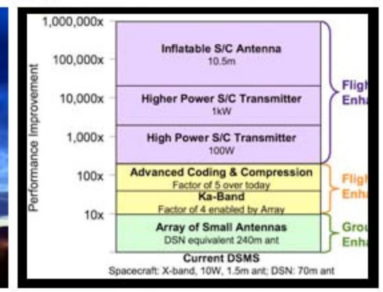
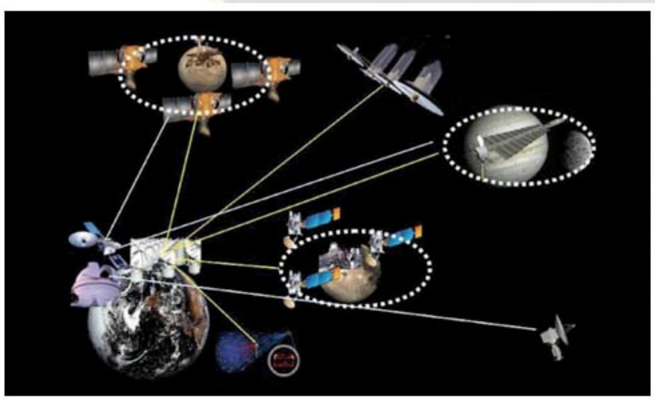
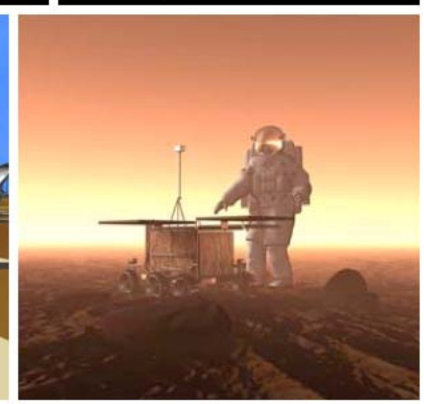
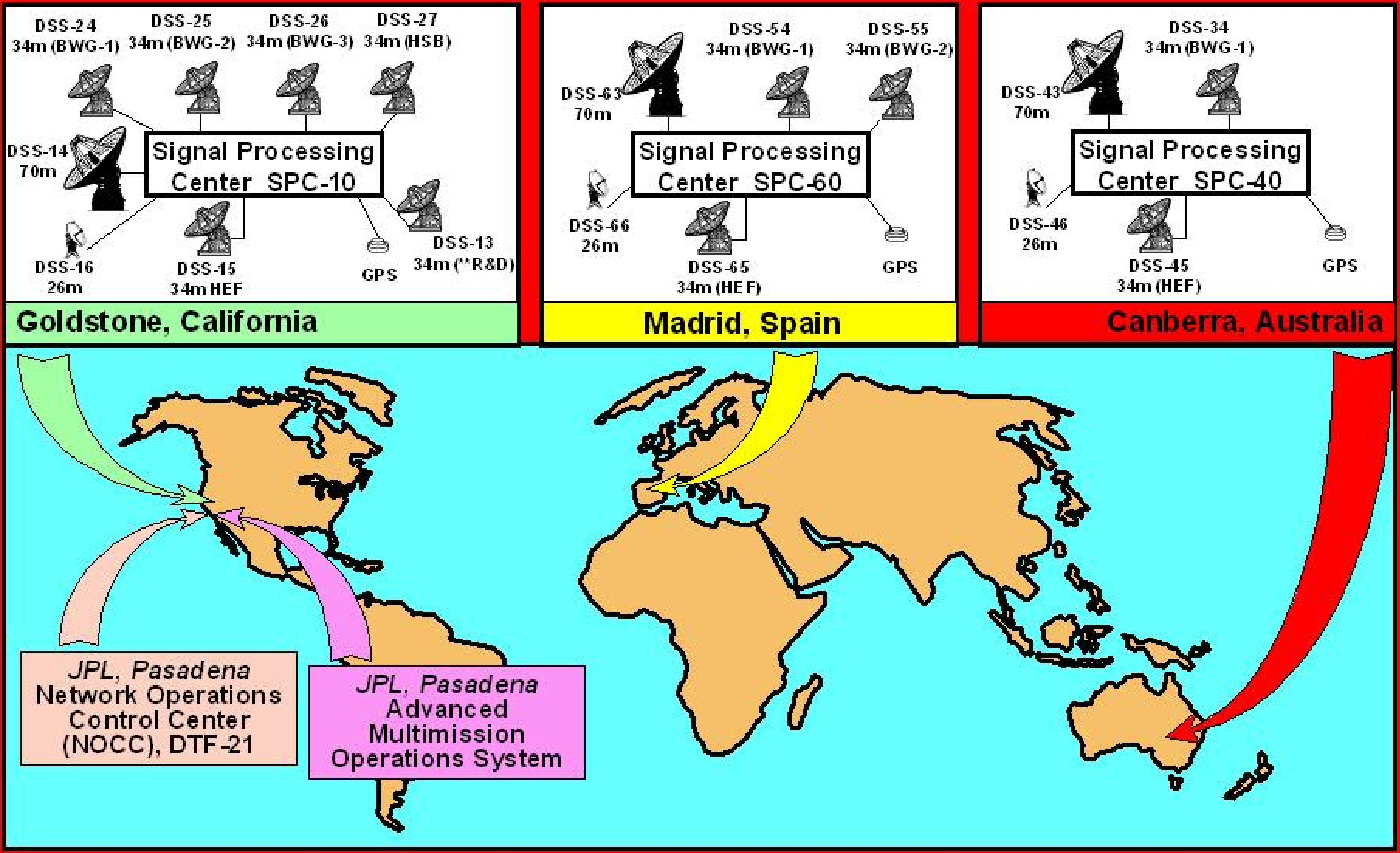








The Deep Space Network (DSN)



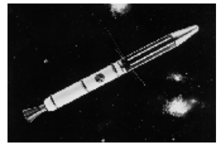
Provides routine S-, X-, and Ka-band communication and navigation support for ~33 missions via 16 large antennas at 3 major tracking sites around the globe.

Past Missions Driving DSN Evolution

Mission Drivers

DSN Evolution

First U.S. Satellite (circa 1958)



Explorer 1

- "Microlock" Tracking & Data Acquistion System (Cape Canaveral, Nigeria, Singapore, and San Diego)

First U.S. Lunar Robotic Missions (circa 1963)

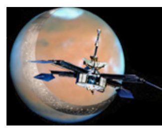
Lunar Pioneers

Rangers

Surveyors

- L-band 26m antennas (Goldstone, Woomera, Johannesburg, and Madrid)

First Mars, Venus, & Human Lunar Missions (circa 1965 - 1969)



Mars Mariners

Venus Mariners

Human Lunar

- S-band 26m antennas
- Forward-error correction coding
- Lower antenna system noise temperatures
- S-band 64m antennas (Goldstone, Canberra, and Madrid)

First Jupiter, Saturn, Mercury, & Mars Lander Missions (circa 1972-1977)

Jupiter & Saturn Pioneers

Venus-Mercury Mariner

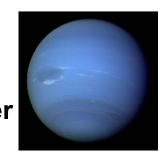
Mars Vikings

Voyagers to Jupiter & Saturn

- Arraying of 26m & 64m antennas
- S- & X-band 34m antennas
- S- & X-band 64m antennas
- Concatenated coding
- Further system noise temperature reductions

First Uranus & Neptune Encounters; First Jupiter Orbiter (circa 1986-1996)

Voyager Uranus Encounter

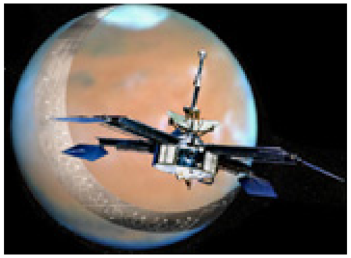


Voyager Neptune Encounter

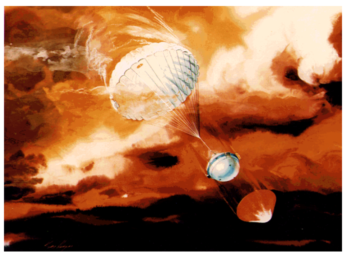
Galileo Jupiter HGA Malfunction

- S- & X-band 70m antennas
- Improved 34m antennas
- Arraying of DSN & Non-DSN assets
- Advanced data compression
- Improved forward-error correction coding

The Changing Mission Paradigm



Brief Flyby Reconnaissance

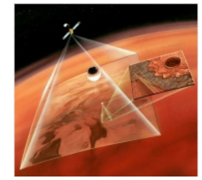


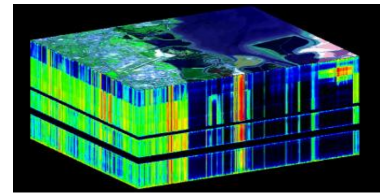
Short-Lived In Situ Probes

Single-Spacecraft Observatories in Low-Earth Orbit.

Orbital Remote Sensing

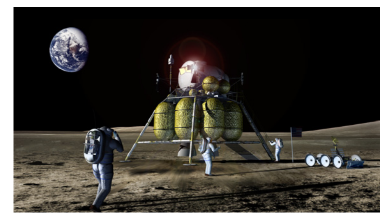
- Long Duration
- High Spatial, Spectral, & Temporal Resolution

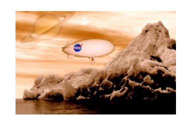




In Situ Exploration

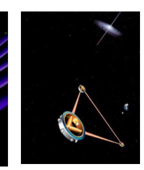
- Human Expeditions
- Long Duration
- Mobility
- Onboard Autonomy

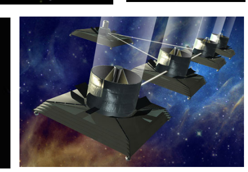




Next Generation Observatories

- More Capability
- Multiple Spacecraft
- Located Further from Earth

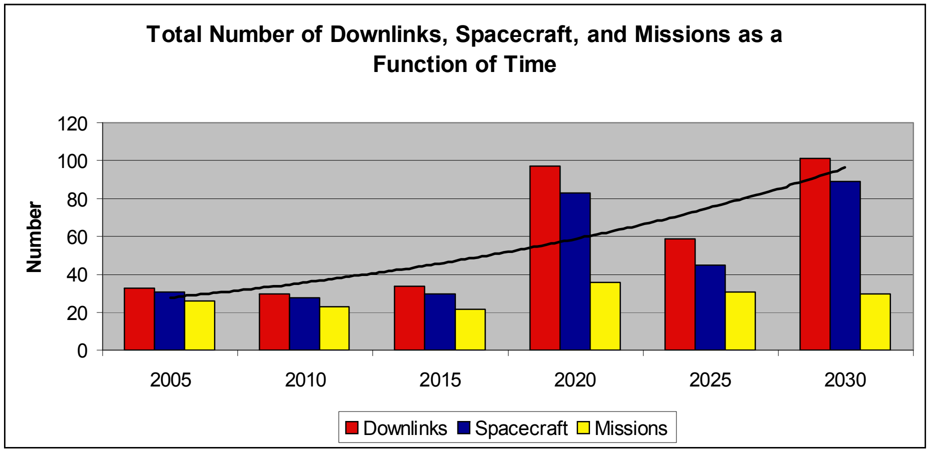




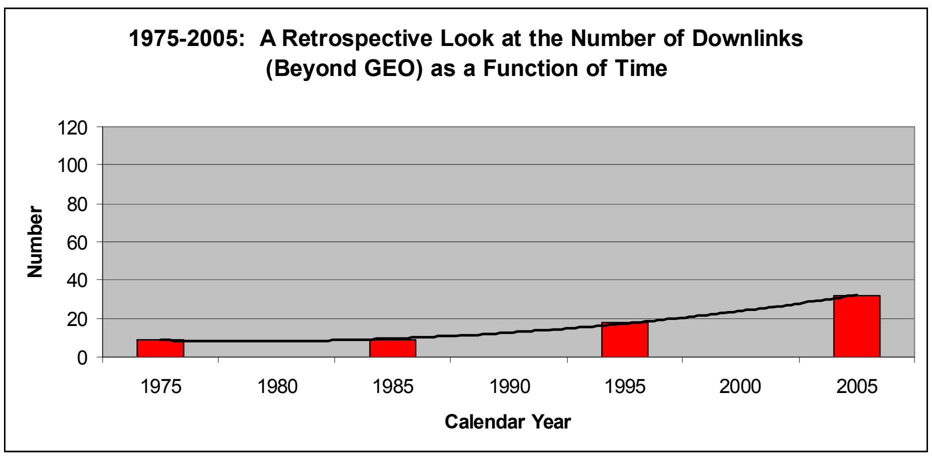
Assessing Future Mission Needs

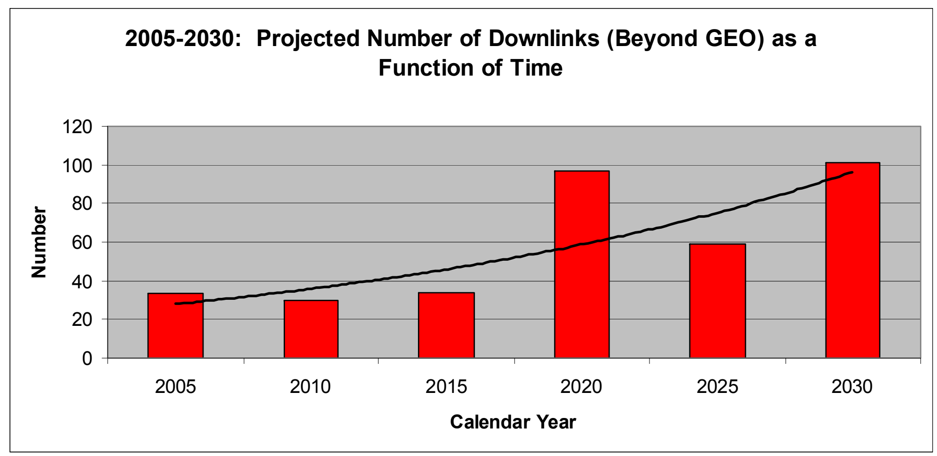
1. Development of a candidate mission set as a function of time.
   - Analysis of latest NASA strategic plans, roadmaps, and official mission set lists
   - Coordination with other NASA mission set development efforts (e.g., Space Communications Architecture Working Group Integrated Mission Set, Agency Mission Planning Model, etc.)
2. Derivation of telecommunications parameters for each mission identified in step 1.
3. Analysis of these parameters as a function of time (generally at 5-year intervals)
   - Number of potential mission-, spacecraft-, and link-supports
   - Downlink and uplink data rates
   - End-to-end link difficulty (data rate times distance squared)
4. Performance of a sensitivity analysis and/or some type of “sanity check” on the trend results.
   - Overestimates can arise from overly optimistic mission roadmaps.
   - Underestimates can arise from a bias toward today’s capabilities when designing the telecom parameters for future mission concepts.
   - Underestimates can arise from a failure to anticipate demand quickly rising to fill available capacity.

Link Support Trends



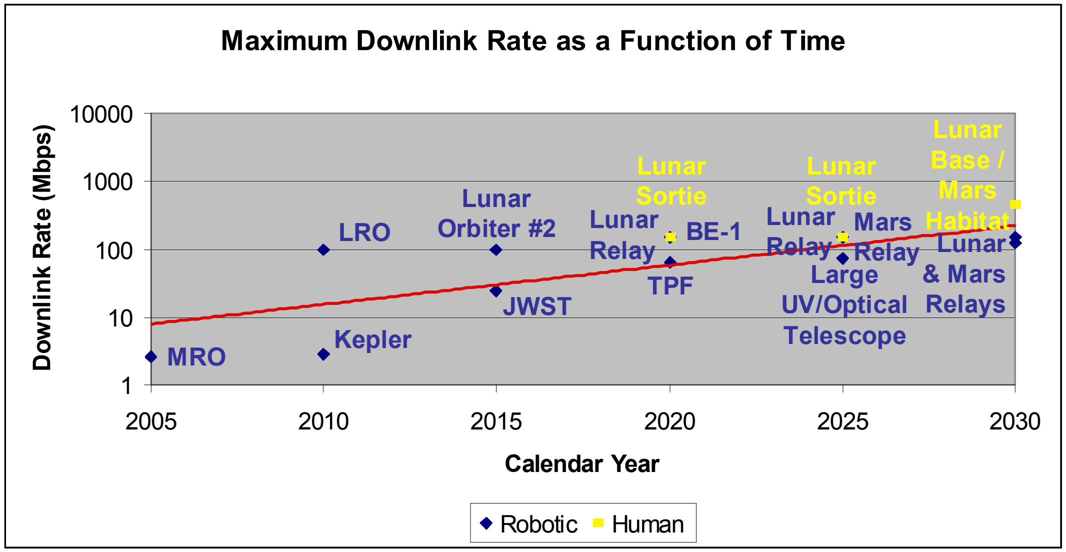
- Number of missions relatively constant over next 25 years.
- But, number of spacecraft and associated downlinks roughly triples.
- Disparity between number of missions and number of spacecraft/downlinks driven by increasing reliance on multi-spacecraft missions.

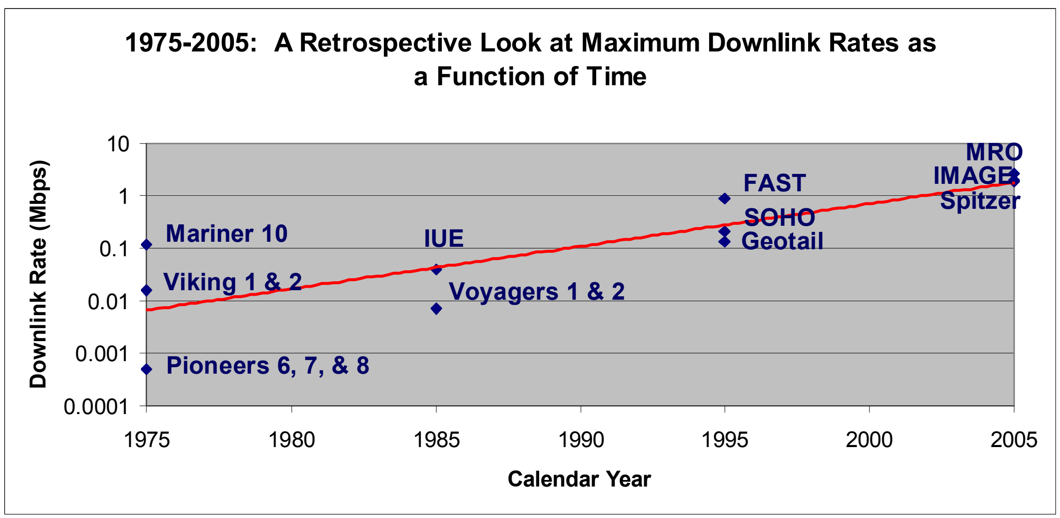




- A “sanity check”: side-by-side comparison of historical and projected downlink trend data reveals curves of similar form and slope.
- The 2020 outlier has since changed with the 34 spacecraft MagCon mission now relegated by NASA HQ to a more distant time frame.

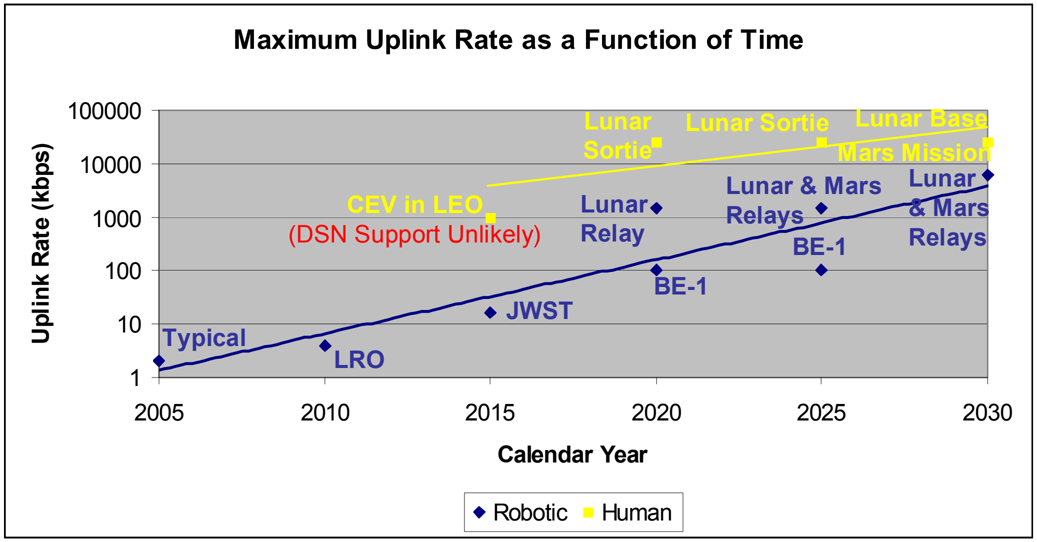
Downlink Rate Trends

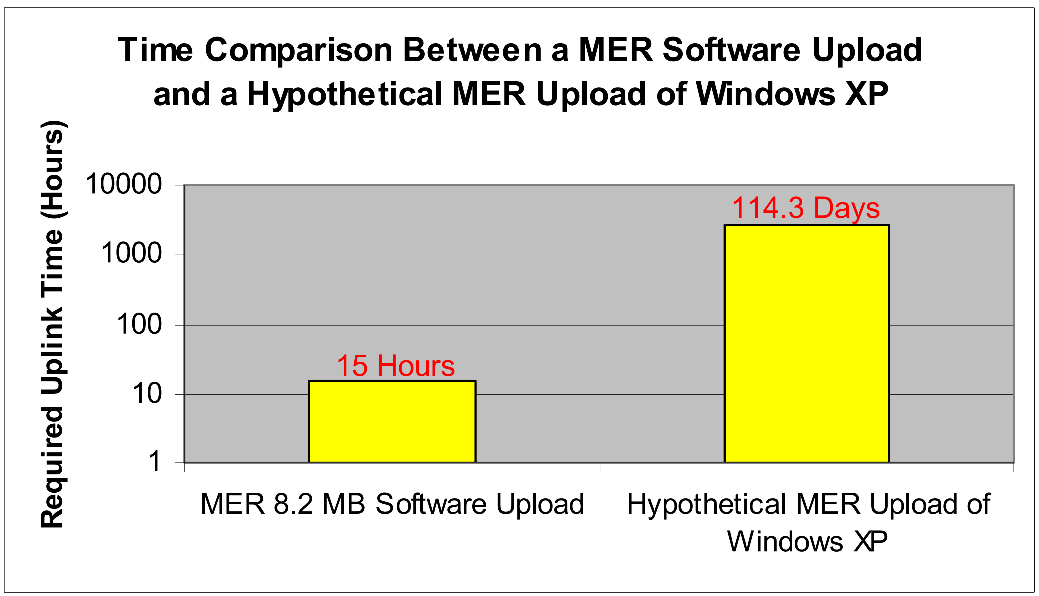




- Downlink rates increase between 1 and 2 orders of magnitude over next 25 years.
- Trend is not dependent on a single class of mission – there are multiple drivers.
- Trend may underestimate future data rates due to traditional telecom design practice relative to spectrum allocation.
- A “sanity check”: historical downlink rates increased more than 2 orders of magnitude over 30 years.
- Hence, above trend appears to be “in the ball park.”

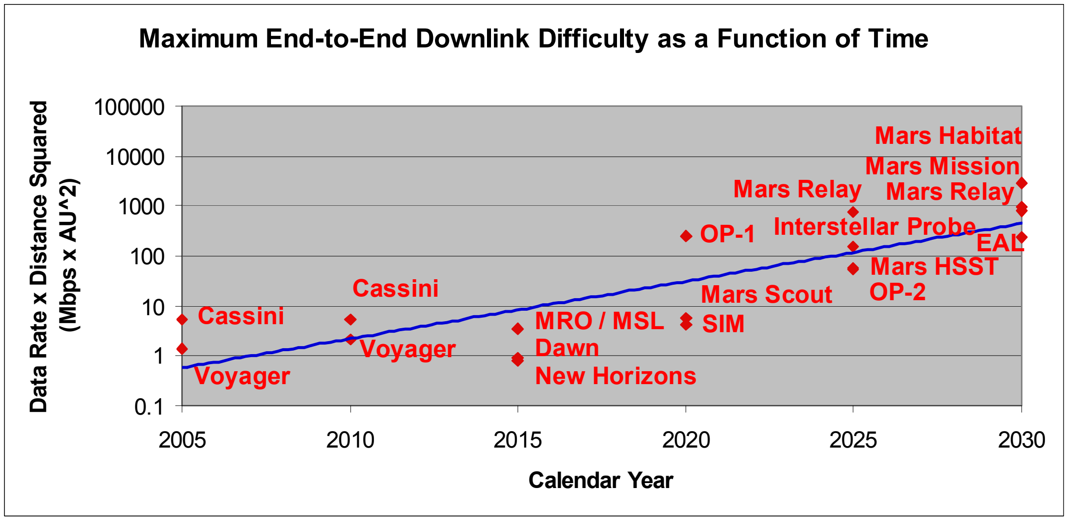
Uplink Rate Trends

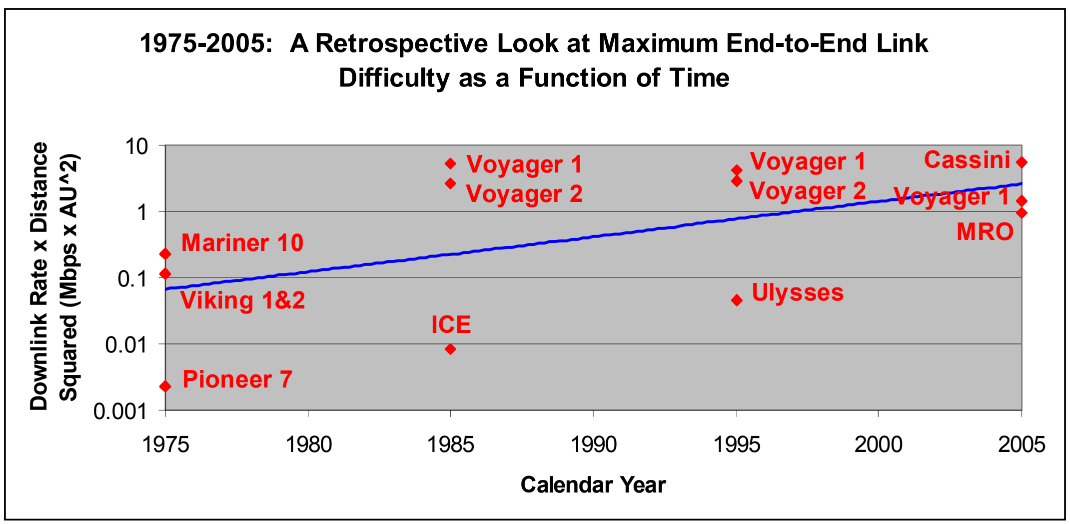




- Human exploration missions drive DSN-supported uplink rates by more than 4 orders of magnitude.
- Results from human-to-human communications involving more symmetric information transfer between sender and receiver.
- Even without human exploration, future robotic missions drive uplink rates by roughly 2 to 3 orders of magnitude.
- No historical analog – uplink rates traditionally around 2 kbps for commanding.
- Greater spacecraft autonomy, however, now necessitating larger and larger software & data uploads.
- Uplink rates must increase to enable timely uploads.

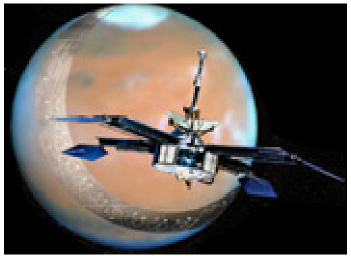
End-to-End Link Difficulty Trends





- End-to-end downlink difficulty increases roughly 2.5 orders of magnitude over next 25 years.
- Multiple classes of drivers apparent.
- Trend before 2015 is driven by extreme distance missions; after, it is driven by high data rate missions.
- Similar trend exists for uplink, though emergency commanding more difficult.
- A “sanity check”: historical end-to-end link difficulty increased roughly 1.5 orders of magnitude in 30 years.
- Driver missions lowered rates when DSN improvements could no longer compensate for increased distances.
- Future planetary remote sensing missions, however, face data volume challenges (i.e., dropping data rates not an option).

Summary: Future Mission Trend Drivers



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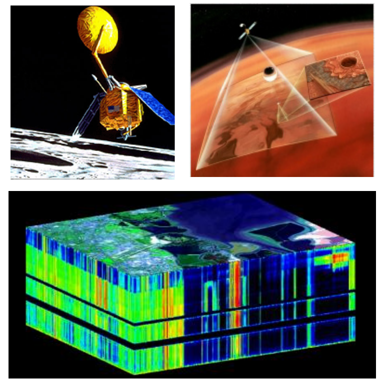
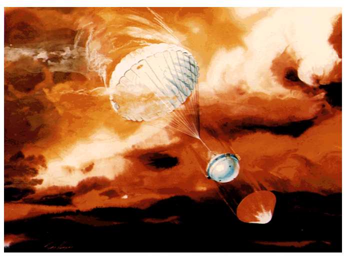


- **Higher fidelity remote sensing drives larger data volumes which, in turn, drive:**
  - Higher downlink rates
  - More difficult end-to-end links



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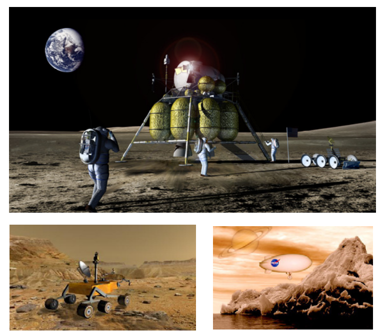

- **Human missions drive uplink & downlink rates**
- **Greater autonomy drives uplink rates**
- **More multi-spacecraft missions drive number of link supports**

Single-Spacecraft Observatories in Low-Earth Orbit.

Next Generation Observatories

- More Capability
- Multiple Spacecraft
- Located Further from Earth

- **More multi-spacecraft observatories drive number of link supports**
- **Greater observatory capabilities drive data rates**

Conclusion: Implications for the DSN

25-Year Trend	Implications for the DSN
1. Roughly 3x as many links to support	• Expanded use of multiple channels per antenna where spacecraft separation distances fall within the same beam • Requirement for additional antennas
2. Downlink rates up to 2 orders of magnitude higher; uplink rates up to 4 orders of magnitude higher	• Requirement for rate-compatible receivers, telemetry processors, decoders, formatters, data recorder forwarding rates, and ground communication lines • Pursuit of more efficient coding, compression, and modulation schemes to fit into existing spectrum bandwidth allocations – and/or advocacy for larger allocations

Implications for the DSN (Continued)

25-Year Trend	Implications for the DSN
3. End-to-end downlink difficulties ~2.5 orders of magnitude greater than today's; similar trend for uplink difficulties	• Continued migration to higher frequency bands (e.g., Ka-band & optical) • Requirement for increasing the effective antenna receiving area of the DSN (e.g., more arraying) • Pursuit of more efficient forward-error-correction codes and data-compression algorithms • Requirement for improved flight-side antennas, transmitters, and relay radio technologies. • Requirement for forward-error-correction coding on the uplink • Pursuit of higher effective isotropic radiated power on the ground, particularly for emergency commanding